AD-A124 004 STRUCTURE FORMATION OF ELECTRO-RHEOLOGICAL SUSPENSIONS IN AN ELECTRIC FIE.. (U) ROYAL AIRCRAFT ESTABLISHMENT FARNBOROUGH (ENGLAND) Z P SHUL'MAN ET AL. JUN 82 1/1

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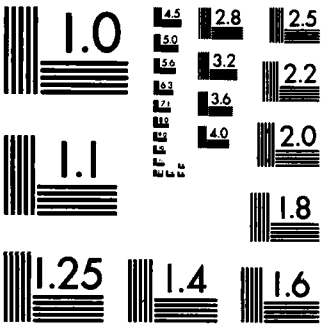

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June 1982

STRUCTURE FORMATION OF ELECTRO-RHEOLOGICAL SUSPENSIONS IN AN ELECTRIC FIELD II. QUANTITATIVE EVALUATIONS

by

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UDC 678.01 : 532.135 : 532.527.2 : 537.212

ROYAL AIRCRAFT ESTABLISHMENT

Library Translation 2089

Received for printing 30 June 1982

STRUCTURE FORMATION OF ELECTRO-RHEOLOGICAL SUSPENSIONS IN AN ELECTRIC FIELD II. QUANTITATIVE EVALUATIONS

STRUKTUROOBRAZOVANIE ELEKTROREOLOGICHESKIKH SUSPENZI V ELEKTRICHESKOM POLE II. KOLICHESTVENNYE OTSENKI

by

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Vestsi Akademii Navuk Belaruskai SSR No.3, p.122-127 (1977)
Seryya Fizika Energetychnykh Navuk

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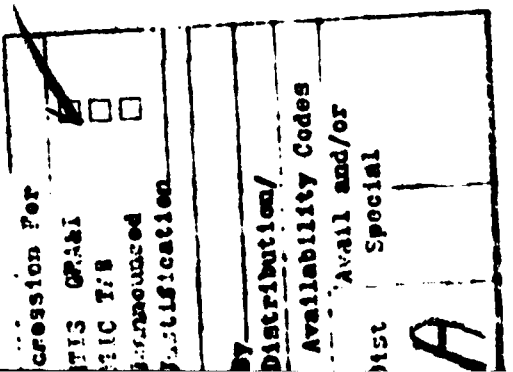
AUTHOR'S SUMMARY

On the basis of the model of an interelectrode bridge which stretches with motion of one of the electrodes, the calculation of an increment of the shear stress in the Couette flow for an electro-rheological suspension with an applied electrical field normal to the shear planes has been carried out. The calculated results are compared with experimental data.



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On the basis of the investigation carried out into the behaviour of particles of an electro-rheological suspension in a strong electric field, it is possible to obtain a quantitative evaluation of the shear stress for Couette flow of such a suspension in an electric field at low shear rates. Consider the supplementary force which must be applied to a moving electrode in order for a bridge to span the electrode gap. The particles in the suspension have a certain conductivity with a potential difference being maintained between the particles.

Initially we calculate the additional resistance of a single bridge containing n particles when the upper electrode is displaced (Fig 1a). The attractive force between the particles is given by:

$$F \approx \frac{\pi\varepsilon\varepsilon_0 V_r^2 r}{2\delta} , \qquad \delta \ll r , \qquad (1)$$

where V_2 is the fall in voltage across the gap
r is the particle radius
δ is the interparticle gap
and ε is the relative permativity of the medium.

In the previous article (1), the above formula was introduced for the case of zero current in the interparticle gap. In the case of current flow, it is still applicable, provided $\delta/r \ll 1$. If the particle and the inter-particle gap have resistances R_1 and R_2 respectively, with a voltage drop across the particle, V_1 and across the electrodes U, then for $n \gg 1$

$$V = V_1 + V_2 = \frac{U}{n} ,$$

and equation (1) becomes

$$F \approx \frac{\pi\varepsilon\varepsilon_0 V^2 R_2^2 r}{2(R_1 + R_2)^2 \delta} . \qquad (2)$$

The additional term arising from the expansion of the bridge is given by

$$P \approx \frac{1}{v} \int_0^{vT} F \frac{x}{H} dx , \qquad (3)$$

where T is the existence time of the bridge
v is the electrode velocity
H is the electrode gap.

For small deflections

$$\sin \alpha \approx \frac{x}{H}$$

and the interparticle gap is given by:

$$\delta \approx \delta_{min} + \frac{x^2}{2nH} \quad , \tag{4}$$

where δ_{min} is the minimum distance between the particles. Substituting (2) and (4) into (3) we obtain:

$$P \approx \frac{\pi\epsilon\epsilon_0 U^2 r}{2n^2 Hv} \int_0^{vT} \left(\frac{R_2}{R_1 + R_2}\right)^2 \frac{x\,dx}{\delta_{min} + \frac{x^2}{2nH}} \quad . \tag{5}$$

The life of the bridge T, is given by

$$\delta_{min} + \frac{(vT)^2}{2nH} \approx \delta_{max} \quad , \tag{6}$$

where δ_{max} is the distance at which the bridge disintegrates.

If N is the number of bridges formed in a unit area of electrode, it is possible to determine the value of the shear stress produced as a result of the bridge expanding.

$$\Delta\tau = \frac{PN}{T} \quad .$$

Substituting for P and T from (5) and (6) we obtain:

$$\Delta\tau = \frac{N\pi\epsilon\epsilon_0 E^2 r^{\frac{5}{2}}}{(\delta_{max} - \delta_{min})^{\frac{1}{2}}} \; J \quad , \tag{7}$$

where

$$J = \int_{\delta_{min}}^{\delta_{max}} \left(\frac{R_2}{R_1 + R_2}\right)^2 \frac{d\delta}{\delta} \quad ;$$

and $E = U/H$, the field strength.

For analytical purposes expression (7) is more convenient if N is replaced by ω, the fraction of particles forming bridges at a given time. The volume occupied by particles in the bridges is $H\Delta S$ and

$$\omega CH\Delta S = n\tfrac{4}{3}\pi r^3 N\Delta S \quad ,$$

where C is the volume fraction of the suspension.

Thus

$$N \approx \frac{3\omega C}{2\pi r^2} \quad , \tag{8}$$

Substituting (8) in (7) we obtain an expression for the increase in shear stress due to the expansion at the bridge:

$$\Delta\tau \approx \tfrac{3}{2} C\varepsilon\varepsilon_0 E^2 \frac{\omega J}{\lambda^2} \quad , \tag{9}$$

where λ is the dimensionless parameter:

$$\lambda = \frac{\delta_{max} - \delta_{min}}{r} \quad .$$

This formula reflects the square law dependence of shear stress on the value of field strength and the linear dependence on solid phase concentration as reported in the literature.

Using equation (9) and estimates of the various parameters, ($\delta_{max} - \delta_{min} = 10\text{Å}$; $r = 0.1\ \mu m$; $\omega \approx 1$; $\varepsilon \approx 2$; $C \approx 1\%$ and $E = 2 \times 10^6$ V/m) the shear stress increase $\Delta\tau \approx 10\ N/m^2$ which agrees with the experimentally observed order of magnitude.

The interactions between these structural factors and their dependence on the velocity of displacement (stress) the strength of the applied field, the activator content and the distance between the electrodes can now be analysed. With an increase in the velocity of displacement (stress), the value of δ_{max} decreases, but it increases with an increase in the activator content. The value of δ_{min} is determined by the field strength and the activator content ϕ , decreasing with increasing field strength. The variation with the activator content depends upon the quantity of the activator, falling to a limit dependent upon the quantity. δ_{max} and δ_{min} are independent of the electrode gap.

The value of ω , the probability of finding a particle in any bridge at a given moment is:

$$\omega = \frac{T}{T + T_n} \quad ,$$

where T_n is the time during which the particle is outside the bridge.

For small shear rates, $\omega \approx 1$ almost all the particles form bridges. As the shear rate increases, ω decreases. Increasing field strength and increasing electrode gap both increase the value of ω . The value of the integral J formula (7) determines δ_{max}, δ_{min} , the conductivity of the interparticle gap and the conductivity of the adsorped layer on the particle. For low quantities of activator the absorbed layer is practically an insulator, *ie* R_1 is very high. If the activator content is large, R_1 is small, but R_2 , the resistance of the gap is also small. As the activator content increases R_2 falls more rapidly than R_1 due to the covering of adsorbed films, for low or high activator contents, therefore, J is small. As a small change in the upper limit of the integral, δ_{max} has no great influence on J , it is possible to assume that J is independent of the shear rate.

From (2) as the voltage U increases (Fig 1b) the force of interaction between the particles increases with the square of U . This increase in force reaches a maximum limit which explains why, at high field strength, the resistance R_2 of the gap falls sharply; the potential drop V_2 across the gap remains almost unchanged, in spite of the

increase of U (formula (1)). Such a phenomenon is discussed in[2] where the Johnson-Rabek effect is analysed. The increase in field intensity above the saturation value E_{sat} has almost no effect on the value of J. It is clear that the value of E_{sat} is determined by the activator content, the quantity of which considerably effects the conductivity of the interparticle gap.

Using the above analysis of the parameters encountered in expression (9) it is possible to analyse the dependence of the shear stress $\Delta\tau$ on these parameters and to compare it with the experimental results. For this purpose expression (9) can be expressed as:

$$\tau - \tau_0 \approx 0.13k\varepsilon CE^2 \quad , \tag{10}$$

where τ_0 is in N/m^2 and is the value of the shear stress of this suspension for a uniform shear rate without an electric field applied, k is the dimensionless group $\omega J/\lambda^{\frac{1}{2}}$. An *a priori* estimation of k shows it to be in the order of several decades. Using (10) it is possible to determine the value under the experimental conditions (Figs 2 to 4).

The dependence of k and $\Delta\tau$ on the shear rate is determined by the values of ω and λ noting that from (6) $T = \lambda^{\frac{1}{2}}/\dot{\gamma}$ so that:

$$k = \frac{J}{\sqrt{\lambda} + \dot{\gamma}T_n} \quad .$$

As the shear rate increases, λ decreases, while the product $\dot{\gamma}T_n(\dot{\gamma})$ increases. For high shear rates $\dot{\gamma}T_n(\dot{\gamma}) > \sqrt{\lambda}$ and the fall in the time which the particles spend in the bridge exceed the reduction in $\lambda^{\frac{1}{2}}$. Therefore, depending on the electrical field strength and activator, content and form, either a monotonous or non-monotonous reduction in k with an increase in $\dot{\gamma}$ can be observed (Fig 2). The dependence of k on $\dot{\gamma}$ for $E = 3 \times 10^6$ V/m for an aerosol suspension with different activators experimentally confirms these conclusions.

The form and content of the activator affect k and $\Delta\tau$ mainly through the value of J. Consequently a significant increase in the shear stress occurs only for an optimum quantity of activator which is almost independent of the field strength and the shear rate, the optimum quantity of activator is determined only by its type. This agrees with the dependence of k illustrated in Fig 3 on the diethylamine and water contents of the aerosol suspensions.

As the field strength increases, the value of J, ω and λ change. However, the behaviour of J is the dominant factor. An electro-rheological effect is observed for $E \approx E_{sat}$. A rise in the field intensity leads to a fall in the value of k (Fig 4). There is an increase in the value of JE^2 and consequently $\Delta\tau$ as the field intensity becomes greater. The deviation from monotonic dependence of k on E observed is governed by the corresponding increase in the values of ω and λ.

An increase in the electrode spacing leads to a reduction in the value of ω and consequently to a reduction in $\Delta\tau$. From (10) it is possible to analyse the effect of volume concentration of the suspension on $\Delta\tau$. Of all the parameters in (10), only ω depends on the concentration when dilute suspensions are involved. Thus, for $\omega \approx 1$, which occurs at low shear rates and high fields, $\Delta\tau$ increases linearly with the concentration of the suspended particles. In other cases, a sharper rise in the value of $\Delta\tau$ as ω increases is observed.

The expression (9) provides quantitative explanation of all the basic rules of the electro-rheological effect for a Couette flow where a low content of disperse phase is involved and provides a correct quantitative evaluation of this effect.

REFERENCES

No.	Author	Title, etc
1	Z.P. Shul'man B.M. Khusid A.D. Matsepuro	Vestsi AN SSSR. Ser Fiz-Energ. Navuk, No.4, 70 (1974)
2	A.D. Stuckes	Proc. Inst. Electr. Eng., Part B, 103, No.8 (1956)

Figs 1&2

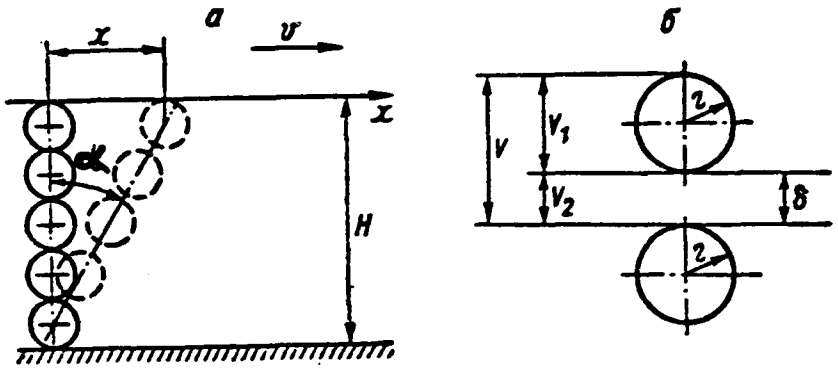

Fig 1 Scheme of the expansion of a bridge of particles with movement of the upper plate (a) and arrangement of neighbouring particles (b)

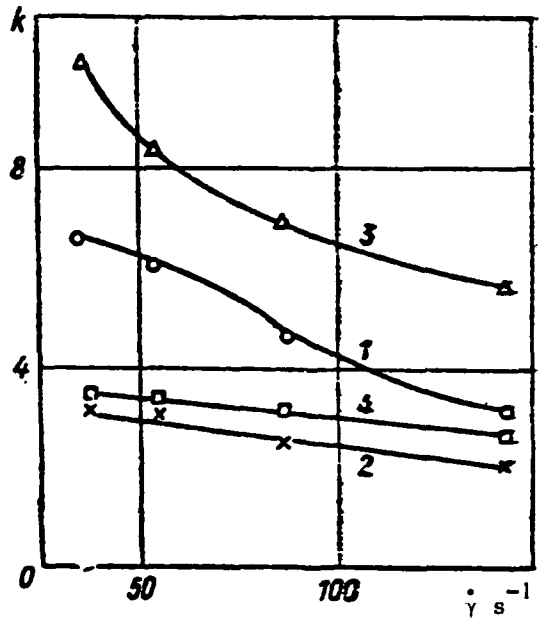

Fig 2 Dependence of the coefficient k on the rate of displacement for an aerosol suspension in cetane, for a particle concentration of 3% by weight; constant field strength 3×10^6 V/m and various contents of activators; water (1, 2); diethylamine (3, 4) as % by weight of aerosol:

(1) 8.1; (2) 5.9; (3) 3; (4) 2

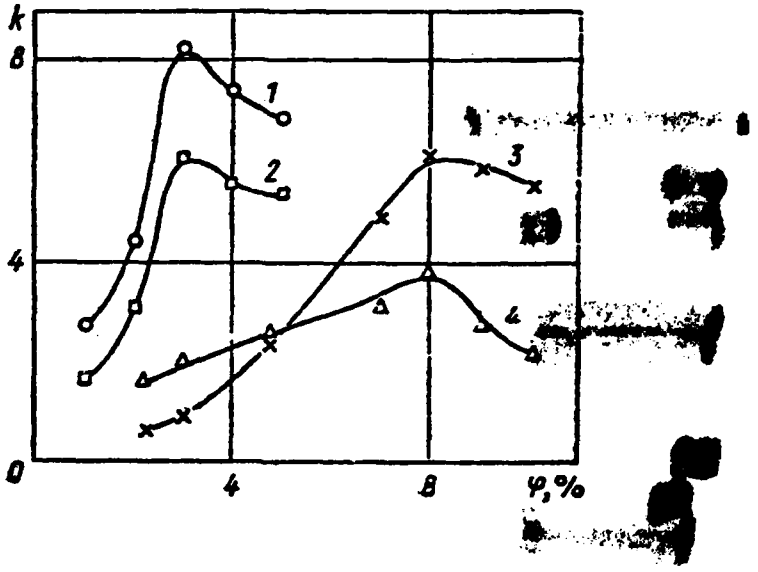

Fig 3 The dependence of the coefficient k on the quantity of activator; diethylamine (1, 2) and water (3, 4), for an aerosol suspension in cetane at a particle concentration of 3% by weight; field strength 3×10^6 V/m; shear rates 53.7 s^{-1} (1, 3) and 143.1 s^{-1} (2, 4)

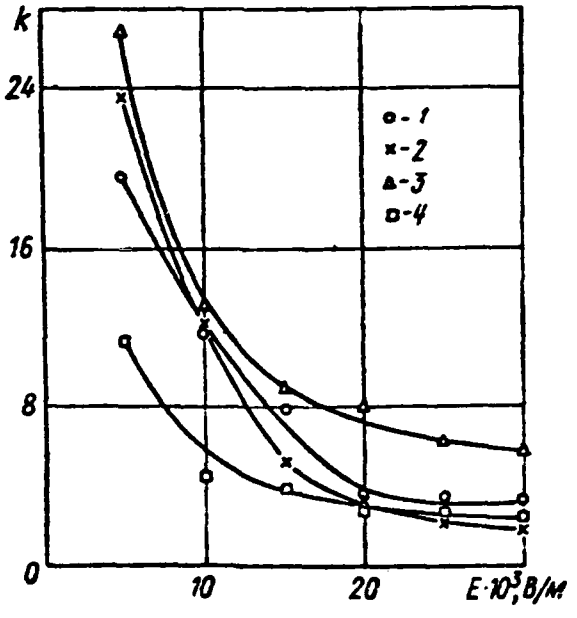

Fig 4 The dependence of the coefficient k on the strength of a constant electric field for an aerosol suspension in cetane at a particle concentration of 3% by weight; shear rate 143.1 s^{-1} activator concentrations of water (1, 2) or diethylamine (3, 4), see Fig 2 (1-4)

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